Classification of montane forest community types in the Cedar River drainage of western Washington, U.S.A.[1]

ROGER DEL MORAL AND JAMES N. LONG

Department of Botany and College of Forest Resources, University of Washington, Seattle, WA, U.S.A. 98195

Received April 28, 1976[2]
Accepted November 29, 1976

DEL MORAL, R., and J. N. LONG. 1977. Classification of montane forest community types in the Cedar River drainage of western Washington, U.S.A. Can. J. For. Res. 7: 217–225.

Vegetation of the Cedar River watershed, located in the Cascade Mountains of western Washington, was analyzed by an agglomerative clustering method followed by discriminant analysis. Stepwise mutliple discriminant analysis provided a means to reallocate stands and assists in the production of a classification scheme and a key to the vegetation types. Ten types are recognized, six from upper-elevation older-growth stands, and four seral types from lower elevation stands logged since 1900. Each type can be identified in the field with a simple key based on cover percentage. The key provides a means for large-scale vegetation mapping with a limited amount of effort.

DEL MORAL, R., et J. N. LONG. 1977. Classification of montane forest community types in the Cedar River drainage of western Washington, U.S.A. Can. J. For. Res. 7: 217–225.

La végétation du bassin de Cedar River, dans la chaîne des Cascades de l'ouest de l'état de Washington, a été analysée par la méthode de l'analyse de groupes suivie de l'analyse discriminante. L'analyse discriminante multiple par étape a fourni un moyen de répartition des peuplements et constitue un outil dans la production d'un schéma de classification des groupements végétaux. On a reconnu 10 types de végétation: 6 en haute montagne, constitués de peuplements agés, et 4 à faible élévation, formés de peuplements exploités depuis 1900. Chaque type peut être identifié sur le terrain au moyen d'une clé simple, basée sur le pourcentage de couvert. La clé fournit un moyen de cartographier la végétation à grande échelle, avec une facilité relative.

[Traduit par le journal]

Introduction

The Coniferous Forest Biome program of the United States component of the International Biological Program (U.S./IBP) had, as a major goal, the definition of the structure, function, and behavior of coniferous forest ecosystems in the Pacific Northwest of the continental United States. One major research site is in the Cedar River drainage in western Washington. Vegetation in the study area is assigned to the *Tsuga heterophylla* and *Abies amabilis* zones defined by Franklin and Dyrness (1973). (Taxonomic nomenclature for vascular plants follows Hitchcock and Cronquist (1973); mosses follow Lawton (1965).) The zones on the Cedar River drainage are analogous to the dry and wet subzones of the coastal western hemlock zone defined by Krajina (1969). Lower-elevation second-growth stands from this survey were grouped subjectively by D. R. M. Scott and J. N. Long (unpublished data). Their classification of these seral stands corresponds to description of similar vegetation by others (e.g., Becking 1954; Franklin and Dyrness 1973). D. R. M. Scott and J. N. Long (unpublished data) assumed that these community types occur in response to an edaphically controlled moisture gradient. Indirect gradient analysis suggests that the stands at higher elevations may be responding to complex gradients associated with elevation as well as moisture.

Subsequent to the vegetation survey, it became apparent that, for many applications, community type classifications were required for the entire range of montane vegetation in the Cedar River watershed. In contrast with the lower-elevation *Tsuga heterophylla* zone, vegetation types (associations, sensu Franklin and Dyrness 1973) have not been carefully defined for the *Abies amabilis* zone of the central Washington Cascades. The only published vegetation study in this zone on the Cedar River drainage is restricted to the Findley Lake basin, where the

[1]The work reported in this paper was supported by National Science Foundation grants no. GB-36810X and BMS74-20744 to the Coniferous Forest Biome, Ecosystem Analysis Studies. This is contribution no. 199 of the Coniferous Forest Biome.

[2]Revised manuscript received November 4, 1976.

vegetation was classified subjectively into three forest types (del Moral 1973). Samples of vegetation from the *Abies amabilis* zone in this area do not fall readily into any of the associations given by Franklin (1966) for the southern Cascades of Washington.

The objectives of this investigation were to construct an objective classification of the vegetation of the Cedar River drainage, one of the intensive study sites of the IBP; to evaluate the classification with respect to its ecological relevance by means of discriminant analysis; to compare our classification of *Tsuga heterophylla* and *Abies amabilis* zone vegetation with the subjective classifications of similar vegetation by other investigators; and to construct a key to vegetation types.

Description of the Study Area

General

The Cedar River drainage in western Washington, U.S.A. (latitude 47°, longitude 121°), extends from the crest of the Cascade Mountains at about 1500 m to Lake Washington near sea level. The drainage above 180 m is included within the City of Seattle watershed and is the location of this study. The stands sampled ranged in elevation from 180 to 1300 m. For the purposes of this study that portion of the drainage between 180 and 600 m is referred to as the lower drainage; that portion above 600 m is referred to as the upper drainage.

Soils and Geology

Soils of the study area are relatively young and infertile. The geological history of the area resulted in the buildup of glacial outwash and till within the lower drainage. Topography is, with a few local exceptions, gentle. The soils derived from the glacial drift are coarse and well drained (Cole and Gessel 1968). The topography of the upper drainage is steep and deeply dissected. The soils are primarily derived from parent material of volcanic origin (Singer and Ugolini 1974).

Site History

Most of the original forests of the Cedar River drainage below about 600 m were harvested before 1924 (Winkenwerder and Thompson 1924). Logging and fires resulted in a mosaic of relatively young stands ranging in age from under 30 to over 100 years. Most of the drainage above 600 m is covered with either old-growth forest ranging in age from 150 to over 300 years or recently logged and replanted areas.

Climate

The study area has a mild maritime climate with about 70% of the precipitation occurring between October and March. Below about 650 m most of the precipitation is in the form of rain, while above this elevation most of it occurs as snow which may accumulate in winter to depths of 2 m or more.

Two locations within the upper and lower portions of the drainage for which weather data are available are the Findley Lake research site (1200 m) and the Thompson research site (220 m). Mean annual precipitation at these locations is 2690 mm and 1360 mm, respectively. Mean temperatures for July and January at the Findley Lake site are 10 and −7 °C whereas mean temperatures for the same months at the Thompson site are 17 and 3 °C.

Methods

Field Sampling

A modification of the reconnaissance method described by Franklin *et al.* (1970) was used. This method permits the rapid evaluation of vegetation units over extensive areas, although it sacrifices some accuracy. In precision it resembles the relevé method of European phytosociologists.

A single 300-m² circular plot was established within each of the 87 homogeneous stands sampled. Among the data obtained in each plot were the following: (1) elevation; (2) slope and aspect; (3) topography and landform; (4) canopy cover of mature trees by species; (5) cover of young trees by species; and (6) cover of each species of shrub, herb, and moss. Cover was estimated visually within the circular plot.

Quantitative Methods

Classification

Cover data for each species were used in the grouping of the samples by minimum dispersion (MDISP). The computing program is that of Goldstein and Grigal (1971). MDISP is based on within-group dispersion with standard distance used as the similarity measure (Orlóci 1967). If there are n_A stands in group A, then the within-group dispersion in A is as follows:

$$Q_A = \frac{1}{n_A} \sum_{j=1}^{n_A-1} \sum_{j'=j+1}^{n_A} d^2_{jj'},$$

where $d^2_{jj'}$ is a measure of distance between stands j and j'. The square of the standard distance measure is defined by

$$d^2_{jj'} = \sum_i \left[\frac{x_{ij}}{v_j} - \frac{x_{ij'}}{v_{j'}}\right]^2,$$

where $v_j^2 = \sum_i x_{ij}^2$.

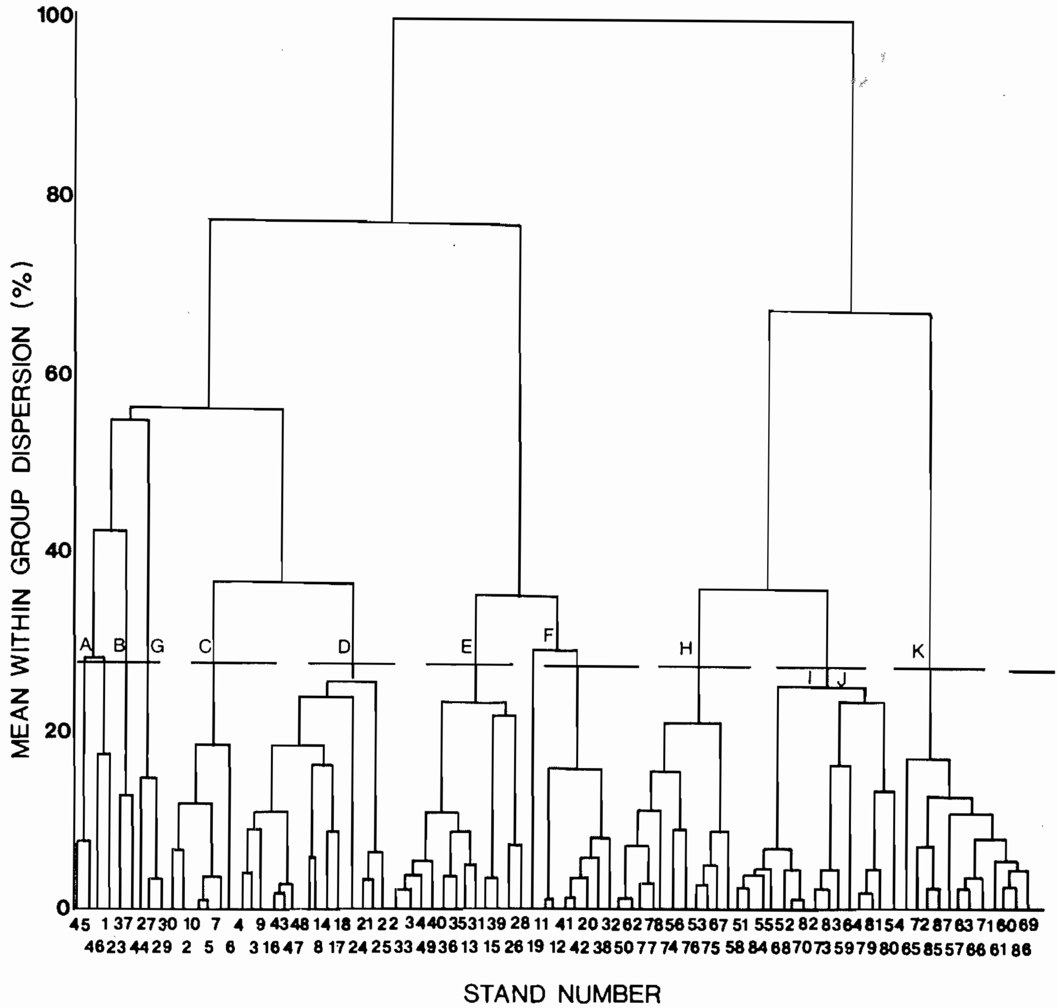

FIG. 1. Dendrogram of results from program MDISP. Scale indicates dispersion within groups as a percentage of total dispersion in the sample. Letters represent group designations.

Each stand is initially considered a separate group. During each iteration, that pair is joined which results in the least amount of within-group dispersion. That pair becomes a new group and the program continues until all stands are joined.

A dendrogram is constructed by recording average dispersion of a group as a percentage of the average dispersion in the total sample for each merger of groups.

Stepwise Multiple Discriminance Analysis (SMDA)

This procedure is described by del Moral (1975) and by Denton and del Moral (1976) following Dixon (1970). Discrimination axes, calculated from an increasing number of variables, are used to optimize the segregation of group means. Individual cases are then assigned to the a priori defined groups on the basis of the discriminant function. A stand is assigned to that group in which it has the greatest probability of occurrence. Information obtained from this analysis includes the rank of species in terms of their importance as discriminators, a table of F values for testing differences between groups, a classification matrix at specified steps (10 and 20 in our analyses), the distance of each stand from the mean position of each group, the probability of occurrence of each stand in each group at specified steps, classification functions at the termination of the analysis, and eigenstructure analysis, and the distribution of stands in canonical space. Canonical dimensions result from the discriminant functions by factor analysis such that each canonical axis contains more variance than any subsequent one and all are mutually orthogonal.

Results and Discussion

Classification

The dendrogram produced by MDISP for 87 stands is shown in Fig. 1, scaled as dispersion

TABLE 1. F values for testing differences between pairs of vegetation types as determined by program MDISP (degrees of freedom, 20, 57). Values greater than 2.23 are significant at the 1% level. Groups A and B are not significantly different

	Group									
Group	A	B	C	D	E	F	G	H	I	J
A	0.00									
B	1.73	0.00								
C	10.93	10.11	0.00							
D	3.71	6.59	10.84	0.00						
E	8.44	3.97	24.56	23.24	0.00					
F	5.89	2.90	15.41	13.97	5.34	0.00				
G	48.04	37.50	68.79	79.24	53.44	57.51	0.00			
H	18.64	19.79	34.62	27.77	55.85	41.19	92.09	0.00		
I	25.15	23.95	38.18	35.41	53.27	43.70	84.96	23.12	0.00	
J	14.71	16.59	28.77	20.65	41.98	32.81	79.70	8.03	8.31	0.00
K	430.91	306.45	495.78	752.08	726.92	599.00	364.07	737.84	607.31	508.35

within groups as a percentage of total dispersion. We recognized eleven groups at the 25% level. The first division separates upland, old-growth stands from lowland, young stands, while subsequent divisions separate the stands into those dominated by one of the four major tree species. There are no stands from either upper or lower samples classified in the other portion of data.

Discriminant Analysis

The 11 groups were subjected to discriminant analysis, terminated after 20 steps. Table 1 presents F values for testing the differences between groups with 20 over 57 degrees of freedom, for which values exceeding 2.23 are significant at the 1% level. (It should be noted that there may be some circularity involved in the tests of between-group differences as these tests are based on the same data used in initially recognizing the group.) On this basis, groups A and B were merged, resulting in 10 groups corresponding to dominance by combinations of the four major tree species. Groups C and D are dominated by *T. heterophylla*; E and F by *A. amabilis*; A, B, and G are intermediate; H, I, and J are dominated by *P. menziesii*; and K by *A. rubra*. It should be noted that this test assumes normally distributed variables, a condition that may not be locally true. Thus it should be used with caution.

The 10 best discriminating species are as follows: trees, *Alnus rubra*, *Pseudotsuga menziesii*, *Tsuga heterophylla*, *Tsuga mertensiana*, and *Acer macrophyllem*; shrubs, *Vaccinium membranaceum* and *Gaultheria shallon*; herb, *Dicentra formosa*; fern, *Polystichum munitum*; moss, *Plagiothecium undulatum*.

Table 2 provides mean cover values for the 31 most common species. Codes for these species are shown in Table 2. The groups may be summarized by dominants as follows: Group AB, Abam–Tshe/Xete–Vame; Group C, Tshe/Vaov/Plun; Group D, Tshe/Vaal/Plun; Group E, Abam–Tsme/Xete–Vame–Vaal; Group F, Abam/Vame–Vaov; Group G, Abam–Tshe/Mefe–Vame; Group H, Psme/Gash/Euor; Group I, Psme/Pomu/Euor; Group J, Psme/Pomu–Libo/Euor–Hysp; Group K, Alru/Pomu–Ptaq/Euor. Figure 2 shows the canonical distribution of 10 community types. The canonical analysis indicates good separation of stands.

A total of 94.9% of the variation is accounted for by the first three dimensions, of which 83.0% occurs in the first. Canonical correlations all exceed 0.98. The plot of stands according to their spatial relationships shows four major groups. One group contains A to F; there is a progression from E and F through AB to C and D. This gradient reflects a shift from *A. amabilis* to *T. heterophylla* dominance. Group G is isolated from this series of groups in the second dimension on the basis of dominance by *Vaccinium membranaceum* and *Menziesii ferruginea* but is more closely related to AB. The *Pseudotsuga*-dominated stands (H, I, and J) are closely grouped, while the *Alnus*-dominated stands are extremely isolated.

Program MDISP provides a satisfactory classification. The stopping rule was arbitrarily set at the 25% dispersion level, except that two groups

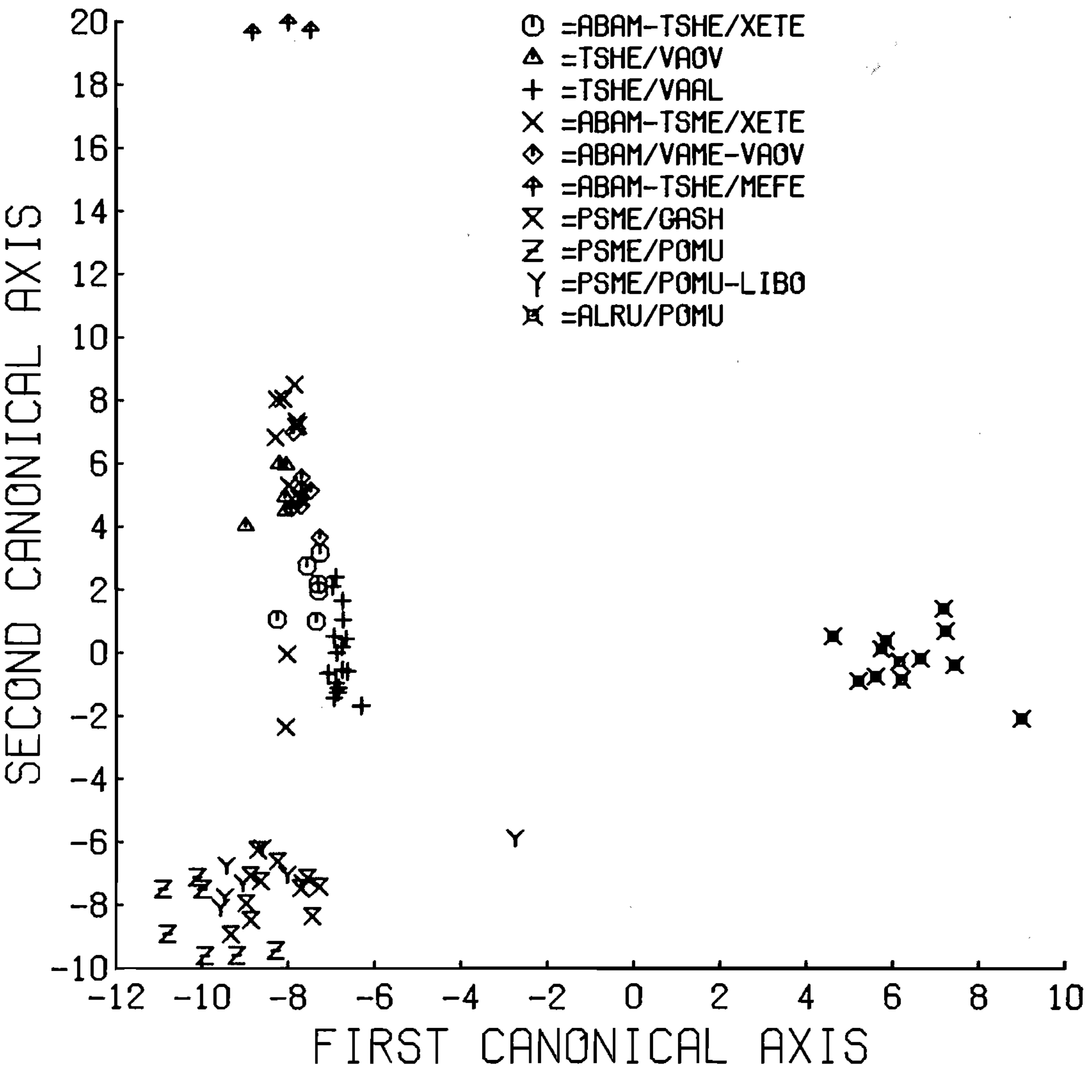

FIG. 2. Canonical distribution of groups produced by MDISP.

that joined at the 24% level were kept separate. There is a slight tendency to chain, but all stands were easily classified. While stand 65 is somewhat unique, it joined to the *Alnus*-dominated group below the 20% dispersion level and is properly included with it. Stands 37 and 44 are recognized as a distinct group (B), which was subsequently merged with A. A high degree of variation is accounted for in the first canonical axis (83%). The distribution of stands in two canonical dimensions reveals the four major groups, which are suggested by dendrograms. After 10 discriminant steps only five reallocations are suggested. MDISP provides a good classification following reallocation. The classification results in few errors at the earlier stages of discrimination compared with our application of other methods.

Description of Community Types

Working in the lower portion of the present study area, D. R. M. Scott and J. N. Long (unpublished data) subjectively determined the presence of three community types that correspond to groups H, I, and K. In addition, we have recognized a group related to I that con-

TABLE 2. Mean cover (in percentage) for common species in vegetation types determined by MDISP

Species	AB (6)	C (5)	D (15)	E (12)	F (8)	G (3)	H (11)	I (7)	J (8)	K (12)	Grand
Trees											
Abies amabilis (Abam)	25.8	28.0	10.5	41.8	76.2	35.0	0	0	0	0	19.2
Abies procera (Abpr)	17.5	0	0.1	0.8	0.1	1.6	0	0	0	0	1.4
Acer macrophyllum (Acma)	0	0	0	0	0	0	0	0	0.9	6.7	1.0
Alnus rubra (Alru)	0	0	0	0	0	0	0	1.6	0	74.6	10.4
Pseudotsuga menziesii (Psme)	12.7	4.2	17.8	0	0	3.3	76.4	71.4	78.1	3.4	27.4
Tsuga heterophylla (Tshe)	31.2	46.0	65.2	1.6	0.1	25.0	9.6	23.7	18.1	3.6	22.4
Tsuga mertensiana (Tsme)	0	0	0	34.0	9.6	5.3	4.5	0	0	0	6.3
Shrubs											
Acer circinatum (Acci)	4.7	0	3.0	0	0	0	3.6	2.6	2.5	7.8	2.7
Berberis nervosa (Bene)	0.2	0.2	3.9	0	0	0	2.7	0	1.3	3.8	1.6
Gaultheria shallon (Gash)	3.3	0	3.0	0	0	0	56.4	2.1	2.8	1.9	8.5
Menziesia ferruginea (Mefe)	0.2	3.0	1.7	6.9	3.5	17.0	0	0.1	0	0	2.3
Oplopanax horridum (Opho)	0	0	4.7	0.1	0	0	0	1.3	0	1.1	1.1
Vaccinium alaskaense (Vaal)	0.2	0	10.0	7.2	3.8	8.7	0	0	0	0	3.7
Vaccinium deliciosum (Vade)	0	0	0	4.7	0	0	0	0.3	0	0	0.6
Vaccinium membranaceum (Vame)	10.6	2.2	2.7	7.7	11.9	73.3	0.9	0.3	0	0	6.1
Vaccinium ovalifolium (Vaov)	0	46.0	5.0	1.3	9.4	0	0	0	0	0	4.6
Vaccinium parvifolium (Vapa)	1.2	3.2	3.1	0.1	0	0	2.4	2.4	3.4	1.1	1.8
Herbs and ferns											
Achyls triphylla (Actr)	4.5	0	3.2	0.2	0.2	1.6	0	0	0.1	0.6	1.0
Clintonia uniflora (Clun)	2.1	1.6	1.9	2.5	3.0	6.7	0	0	0	0	1.4
Festuca sp. (Fesp)	0	0	0	0	0	0	0	0.1	0.1	4.2	0.6
Linnaea borealis (Libo)	0.3	1.2	2.3	0	0	1.7	6.1	0.1	10.9	0.1	2.4
Polystichum munitum (Pomu)	0	0	0.3	0	0	0	3.7	65.0	23.0	58.3	15.9
Pteridium aquilinum (Ptaq)	0.3	0	0.1	0	0	0	8.0	1.8	1.8	8.4	2.5
Rubus ursinus (Ruur)	0	0	0.1	0	0	0	0	2.7	3.3	2.2	2.2
Tiarella trifoliata (Titr)	0	0.2	0.6	0.2	0.1	0	0	0.1	0	0.5	0.3
Tolmiea menziesii (Tome)	0	0	0	0	0	0	0	0	0	1.3	0.2
Xerophyllum tenax (Xete)	17.8	0.4	1.7	12.9	5.0	0	0	0	0	0.4	3.8
Mosses											
Eurhynchium organum (Euor)	0	0	1.9	0.8	0	2.0	39.1	18.5	27.5	9.3	10.8
Hylocomium splendens (Hysp)	0	0	1.1	0	0	0	3.1	1.0	12.2	1.4	2.0
Mnium insigne (Mnin)	0	0.2	0.1	0	0	0.3	0.5	1.4	0.8	0.8	0.4
Plagiothecium undulatum (Plun)	6.0	44.0	16.5	0.8	0.4	8.3	0	0	0	0	6.2

tains more *Linnaea borealis* and less *Polystichum munitum*. Our classification of the data is nevertheless comparable with the earlier subjective classification. The correspondence between our objective classification of the lower-elevation stands and commonly recognized subjective classifications for the region (e.g., Becking 1954) provides circumstantial evidence for the validity of our classification of the higher-elevation old-growth vegetation. We have defined six community types in the older stands found at higher elevations on the Cedar River drainage and suggest that each of these is as coherent as the commonly recognized *Pseudotsuga*- or *Alnus*-dominated community types. A key for the field identification of these community types is presented in Table 3. The associations can be readily recognized on a floristic basis from this key.

Table 4 provides a descriptive summary of the major factors characterizing each community type. Community types A to G are all old-growth vegetation in the upper margins of the *Tsuga heterophylla* zone and in the *Abies amabilis* zone (sensu Franklin and Dyrness 1973). Dyrness *et al.* (1974) have prepared a preliminary classification of forest associations in central Oregon. Their level of aggregation is similar to that in our study, but since many subordinate species differ, the community types are not comparable. Only our Abam/Tsme and Abam/Vame types have counterparts in their study.

TABLE 3. Key to vegetation types of the Cedar River watershed

I. Vegetation dominated by climax conifers species: *Abies amabilis*, *Tsuga mertensiana*, or *T. heterophylla*
  2. *Tsuga heterophylla* common to dominant
    3. *Tsuga heterophylla* common, *Abies amabilis* common
      4. *Vaccinium membranaceum* dominant, *Menziesia ferruginea* over 5% cover, *Xerophyllum tenax* absent........association G
      44. *Vaccinium membranaceum* present, never dominant, *Menziesia* rare or lacking, *Xerophyllum* present; canopy dominance mixed......association AB
    33. *Tsuga heterophylla* dominance, *Abies amabilis* present but does not share dominance
      4. *Vaccinium ovalifolium* over 20% cover, *Plagiothecium undulatum* over 30%, *Abies amabilis* over 15%........association C
      44. *Vaccinium ovalifolium* under 15%, *Plagiothecium undulatum* under 25%, *Abies amabilis* under 25%........association D
  22. Cover of *Tsuga heterophylla* from 0% to 5%
    3. *Abies amabilis* and *Tsuga mertensiana* share dominance, *Xerophyllum tenax* or *Vaccinium deliciosum* present........association E
    33. *Abies amabilis* strongly dominant, *Vaccinium ovalifolium* over 5% cover (*Vaccinium deliciosum* absent)........association F

II. Vegetation dominated by seral species: *Pseudotsuga menziesii* or *Alnus rubra*; *Abies amabilis* and *T. mertensiana* absent
  2. *Pseudotsuga menziesii* dominant, *Eurhynchium oreganum* common; *Alnus rubra* rare or lacking
    3. *Gaultheria shallon* dominant ground cover (over 50%)............association H
    33. *Gaultheria shallon* rare or lacking; *Tsuga heterophylla* common
      4. *Linnaea borealis* and (or) *Hylocomium splendens* over 5% cover, *Polystichum munitum* common, but under 50% cover........association J
      44. Both *Linnaea borealis* and *Hylocomium splendens* rare (under 4% cover), *Polystichum munitum* over 50% cover........association I
  22. *Alnus rubra* canopy dominant, *Polystichum munitum* common......association K

TABLE 4. Summary of the major factors characterizing the vegetation types of the Cedar River watershed.

Group	Community type	Elevation (m)	Aspect	Slope	Age (years)	Comments
AB	Tshe–Abam/Xete	900–1200	W–SE	Moderate to steep	250	Not wholly homogeneous, two groups joined by discriminant analysis
C	Tshe/Vaov	700–900	E–NW	Gentle	250–300	Greater Abam dominance than D
D	Tshe/Vaal	600–1000	W–NE	Gentle to moderate	250	Well developed Abam regeneration
E	Abam/Tsme/Xete	900–1200	Various	Moderate	150–250	Regeneration mainly Abam
F	Abam/Vame–Vaov	700–900	Various	Steep	200–250	Strong Abam dominance
G	Abam–Tshe/Vame	900–1200	Various	Moderate		Differs from F in high amounts of Tshe
H	Psme/Gash	190–400	W–S–E	Gentle	38–73	Characteristic of xeric habitats within the Tshe zone
I	Psme/Pomu	280–490	Various	Gentle to moderate	31–50	Seral stands, hemlock regeneration
J	Psme/Pomu–Libo	190–550	Various	Gentle	40	Similar to H except in relatively high abundance of Libo
K	Alru/Pomu	170–520	Various	Gentle	39–50	Such stands are exceedingly common in Puget Sound lowlands particularly on moist and recently disturbed sites

Their study was confined primarily to climax and late seral vegetation whereas we have no late seral or climax stands below 700 m in the *T. heterophylla* zone. The remaining community types are from low-elevation seral stands.

The ecological relationship between the community types are complex. The Alru/Pomu type is unique because it is the only type not dominated by conifers. Among the low-elevation seral associations, it also represents the moist end of a soil moisture gradient (Cole and Gessel 1968). The dry end of this gradient is represented by the Psme/Gash type.

Among the higher-elevation old-growth types, there are two important environmental complexes. Indirect gradient analysis by Long (1976) suggests some factor(s) correlated with elevation is responsible for much of the variation between community types. The Abam–Tsme/Xete and Abam/Vame–Vaov types represent the upper end of this postulated gradient. The three Tshe-dominated associations occupy the lower end of the gradient with the Abam–Tshe/Vame–Mefe association transitional between the upper and lower groups. The importance of elevation in explaining vegetation distribution within the Tshe and Abam zones has been suggested by several workers (Thornburgh 1969; Fonda and Bliss 1969; Dyrness *et al.* 1974).

A second environmental factor that affects the distribution of the upper slope types is available soil moisture. The Tshe-dominated associations are apparently most responsive to this postulated gradient with the Tshe–Abam/Xete/Vame association and the Tshe/Vaov/Plun association representing the drier and more mesic ends of the gradient, respectively.

The vegetation types recognized are as distinct as can be expected for data obtained from a complex spatial and temporal gradient system. Our first objective, to construct an objective classification, has been met. The judicious use of discriminant analysis refined the original classification and produces an ordination of the classes. This ordination can be related to environmental features and agrees with earlier ordination studies. Thus our second objective is met. Our third objective is met but produces an unforeseen result. The classification agrees well with regional and local subjective classifications in the *Tsuga heterophylla* zone. Our classification for stands in the *Abies amabilis* zone produces groups of similar variability to those in the *Tsuga heterophylla* zone, but only two are similar to types described elsewhere. The vegetation of the *Abies* zone apparently changes more geographically in terms of subordinate species than associations at lower elevation. Our last objective, to produce a vegetation key based on cover, was achieved and facilitated by discriminant analyses. The species best distinguishing between groups are identified by this method and this identification suggests an efficient strategy in key construction.

The combination of classification with discriminant analysis is at worst comparable with subjective classifications and at best a significant improvement in terms of cost efficiency and the allocation of transitional stands.

BECKING, R. W. 1954. Site indicators and forest types of the Douglas-fir region of western Washington and Oregon. Ph.D. Thesis, Univ. Washington, Seattle, WA.

COLE, D. W., and S. P. GESSEL. 1968. Cedar River research. A program for studying pathways, rates, and processes of elemental cycling in a forest ecosystem. For. Resour. Monogr. Contrib. No. 4, Univ. Washington, Seattle, WA.

DEL MORAL, R. 1973. The vegetation of Findley Lake Basin. Am. Midl. Nat. **89**: 26–40.

——— 1975. Vegetation clustering by means of ISODATA: revision by multiple discriminant analysis. Vegetatio, **29**: 179–190.

DENTON, M. F., and R. DEL MORAL. 1976. Comparison of multivariate analyses using taxonomic data of *Oxalis*. Can. J. Bot. **54**: 1637–1646.

DIXON, W. J. 1970. B. M. D. Biomedical Computer Programs. Health Sciences Computing Facilities, Department of Preventive Medicine, University of California, Los Angeles, CA.

DYRNESS, C. T., J. F. FRANKLIN, and W. H. MOIR. 1974. A preliminary classification of forest communities in the central portion of the western Cascades in Oregon. Coniferous Forest Biome Bulletin No. 4, University of Washington, Seattle, WA.

FONDA, R. W., and L. C. BLISS. 1969. Forest vegetation of the montane and subalpine zones, Olympic Mountains, Washington. Ecol. Monogr. **39**: 271–301.

FRANKLIN, J. F. 1966. Vegetation and soils in the subalpine forest of the southern Washington Cascade Range. Ph.D. Thesis, Washington State Univ., Pullman, WA.

FRANKLIN, J. F., and C. T. DYRNESS. 1973. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, USDA For. Serv., Portland, OR.

FRANKLIN, J. F., C. T. DYRNESS, and W. H. MOIR. 1970. A reconnaissance method for forest site classification. Shinrin Richi, **12**: 1–14.

GOLDSTEIN, R. A., and D. F. GRIGAL. 1971. Computer programs for the ordination and classification of ecosystems. ORNL-IBP-71-10.

HITCHCOCK, C. L., and A. CRONQUIST. 1973. Flora of the Pacific Northwest. Univ. Washington Press, Seattle, WA.

KRAJNA, V. J. 1969. Ecology of forest trees in British Columbia. Ecol. West. North Am. **2**: 1–146.

LAWTON, E. 1965. Keys for the identification of the mosses of Washington and Oregon. Bryologist, **68**: 141–184.

LONG, J. N. 1976. Forest vegetation dynamics within the *Abies amabilis* zone of a western Cascades watershed. Ph.D. Thesis, Univ. Washington, Seattle, WA.

ORLÓCI, L. 1967. An agglomerative method for the classification of plant communities. J. Ecol. **55**: 193–206.

SINGER, M., and F. C. UGOLINI. 1974. Genetic history of two well-drained subalpine soils formed on complex parent materials. Can. J. Soil Sci. **54**: 475–489.

THORNBURGH, D. A. 1969. Dynamics of the true fir–hemlock forests of the west slope of the Washington Cascade Range. Ph.D. Thesis, Univ. Washington, Seattle, WA.

WINKENWERDER, H., and A. E. THOMPSON. 1924. Report of the reforestation of the Cedar River watershed (with special reference to the upper division). Water Department, City of Seattle, WA.